CUPOLA TESTS MADE DURING A COURSE
IN
ADVANCED METALLURGY

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ARMOUR INSTITUTE OF TECHNOLOGY

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R E P O R T

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By

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REPORT OF CUPOLA TESTS MADE DURING A COURSE IN ADVANCED METALLURGY.

A THESIS.

PRESENTED BY

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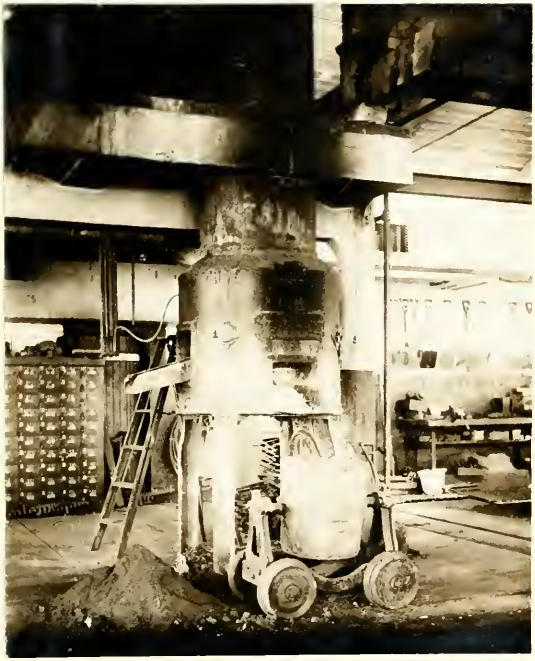

Fig.1.

Foundry Cupola Used In Tests.

REPORT OF CUPOLA TESTS MADE DURING A COURSE IN ADVANCED METALLURGY.

OBJECT OF THE TESTS.

The tests, the results of which, are given in this paper were held in the Foundry of the Armour Institute of Technology during the melting of charges of iron in a Whiting Foundry Cupola. Each test extended over the time necessary to bring the metal to fusion temperature and to tap the entire charge after fusion. A complete set of data was secured for each heat with the following objects in view; (1) to afford means of studying the changes undergone by iron when remelted, (2) to endeavor to account as completely as possible for all heat which was supplied to the Cupola during the fusion, and (3) to investigate the manner of conducting the process with a view of noting the conditions which must be met with in order to produce the highest efficiency of the cupola.

APPARATUS USED IN TESTS.

In carrying out the tests mentioned above, apparatus for four purposes are needed. These are as follows; (1) apparatus for weighing the input and output of the cupola, (2) apparatus for the measurement of blast pressure, (3) apparatus for measuring the temperature of the molten iron and of the gases leaving the cupola, and (4) apparatus for securing samples of the gases.

Fig.2.

Apparatus Used In Measuring The Total Blast Pressure.

1. For weighing the input and output of the cupola, an ordinary Fairbanks Platform Scale was used, the instrument being capable of registering the weights of substances correctly to 1/10th of a pound. As much less accuracy than that, which the scale was capable of giving, was required (the weighings being only recorded to a half pound) the apparatus proved both efficient and reliable for use in the tests.

2. The measurements which had to be made of the blast pressure, were, first, the total pressure exerted by the blast, and secondly, its velocity head. To determine the total pressure, or the sum of the component pressures due to the velocity and compression of the confined air, an ordinary manometer was used, the manometer being connected as shown in Fig.2. By reference to the figure mentioned above, the manometer will be seen to consist of a glass tube of narrow bore and about 24" in height. Connected to the lower end of the glass tube is a "U" shaped tube of brass, free end of which is made to extend as high as the lower level of the glass tube. The brass tube is filled with water, causing two balanced columns to be formed in the arms of the manometer. A calibrated scale is affixed to the manometer and denotes the difference in height of the two columns, expressing the amount of pressure causing the difference in ounces of water.

Fig.3.

The Pitot Tubes.

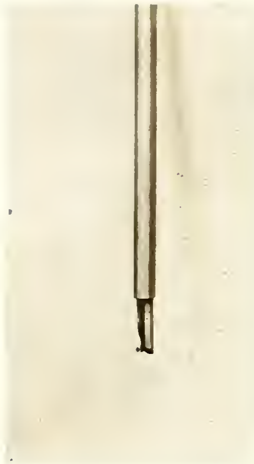

Fig.4.

Lower End of Pitot Tubes.
Tube A to the left.

Fig.5.

Draft Gauge Used With Pitot Tubes.

The free end of the brass tube is connected by rubber tubing to the space in the cupola into which the blast enters before mixing with the charge. Any pressure within the cupola will cause the column of water nearest it to be depressed, the amount depending upon the magnitude of the pressure, while the height of the second column will be increased by the same amount. If a reading be taken of this height by means of the graduated scale, this pressure may at once be determined. In making blast calculations it is more convenient to express pressure in inches of water than in ounces. In order to make this change it is only necessary to multiply the manometer reading by 1.735 (the number of inches of water corresponding to a pressure of 1 oz. of water) the result giving the pressure in the desired unit. This instrument is capable of registering with accuracy pressures as low as 1/10 of an ounce or .17" of water.

For determining the velocity head, or the pressure exerted by the blast by reason of its velocity, the Pitot tubes are used, the tubes being connected to a draft gauge or manometer. These (fig.3 and 4) consist of two tubes and fittings which permit of their being introduced into the pipe conveying the blast. The lower end of tube A is made to face in the direction of the blast , its upper end being connected to the lower one of the manometer.

Fig.6(a).

Thwings Radiation Pyrometer.

Fig.6 (b).

Wheatstone Bridge Used With"Whipple Temperature Indicator."

The tube records when in this position the dynamic head of the blast i.e. the sum of the pressures due to the velocity and confinement of the air. The upper end of tube B is connected to the second opening of the Manometer. This being so constructed as to lie at right angles to the direction in which the air is flowing through the pipes, records that pressure of the blast due to its confinement alone, or its static head. As the pressures exerted by the air in tubes A. and B. are made to oppose each other, the Manometer will record their difference or the velocity head.

DYNAMIC HEAD + STATIC HEAD = STATIC + VELOCITY HEAD - STATIC = VELOCITY HEAD.

An oil lighter than water is used as the liquid in the manometer, and ~~by making~~ as the vertical rise of the manometer tube is extremely gradual, this head can be easily read to 1/100 of an inch.

3. APPARATUS FOR TEMPERATURE MEASUREMENT.

For measuring the temperature of the hot gases leaving the cupola an electric pyrometer is used. This consists of a coil of fine platinum wire wound on a mica frame and mounted in a porcelain tube. The extremities of these wires are connected in series with two dry cells and a special form of a Wheatstone Bridge, the entire arrangement forming a closed circuit. It has been found that resistance in a wire varies directly with the temperature of the wire, hence if wires having a known

resistance at a definite temperature are heated to any other temperature, a proportionality can be made by which the second temperature can be calculated. In the Whipple Temperature Indicator such as was used in the experiments on the cupola, the Wheatstone bridge has been calibrated to indicate this temperature directly, the limit of the graduations on the instrument being 1200°C.

For measuring the temperature of the molten iron a radiation pyrometer was used. This instrument depends upon the fact that if two wires of different metals are soldered together so as to form a closed circuit, and heated at the union, an e.m.f. will be produced proportional to the degree to which the wires have been heated. If a volt meter is attached to the circuit its readings will be a measure of the temperature of the wires. Thwings radiation pyrometer is an instrument of this type. It consists (see fig.6) of the two wires which are encased in a large iron tube, the union alone being exposed to the air. To these wires a Millivoltmeter is connected in series, the voltmeter being calibrated to read temperatures directly. To operate this form of pyrometer it is only necessary to point the exposed end of the wires directly at the

Fig.7.

Apparatus For Securing Gas Samples.

heated object and about two feet away from it. The radiation temperature can then be read on the Millivoltmeter. As the amount of heat radiated from a heated body bears a definite relation to the total heat and temperature of the body, this instrument can be used to determine the actual temperature of the substance itself. For instance, to obtain the temperature of molten iron we simply find its radiation temperature by means of the pyrometer and multiply the result obtained by 1.46 the product giving the required temperature.

4. APPARATUS FOR OBTAINING GAS SAMPLES.

To obtain samples of the gases leaving the cupola an apparatus such as shown in fig.7 was used. The rubber tube to the left of the pump is connected to a copper tube extending into the cupola and above its charging door. The second rubber tube leading from the pump is connected to a sampling bottle which is filled with water. Gas is pumped out of the cupola displacing the water in the sampling bottle the water flowing out of the lower opening. After all of the water has been displaced, the two openings of the bottle are immediately closed by clamps, and the sample is ready to be taken for analysis.

PROCEDURE.

In beginning a heat the bottom of a cupola is covered to a height of about 6" with shavings and dry wood. A bed charge of 300 pounds of coke is then placed immediately upon the wood. After the coke, and before lighting the fire, about 900 pounds of iron are placed upon the coke. The fire is then lighted and allowed to burn for some time under natural draft until it is evident that the coke is well ignited and the iron fairly hot. The blast is then turned on, the tests beginning simultaneously with its commencement. Readings are immediately taken of the manometer, draft gauge, and temperature indicator, each reading being repeated at five minute intervals throughout the heat. Gas samples likewise are taken, but at sufficient intervals so as to cover the entire time occupied by the operation. The opening in the cupola for tapping the iron is kept open during the first few minutes that the blast is on, while the man in charge of the heat by vigorous poking makes sure that the charge is as compact and close to the coke as possible. When melted iron begins to trickle down through the coke, this door is closed.

Ten minutes after starting the blast, the iron is usually molten and ready for the first tapping. It is however, comparatively cold and unsuited for most moulds, as it solidifies too quickly, forming imperfect castings. As soon as the iron is tapped, its temperature is taken by means of the radiation pyrometer, readings being taken at each subsequent tapping. Charges of limestone, coke, and iron, are added to the cupola in rapid succession, the speed of addition, being just rapid enough to keep the level of the charge on a level with the charging door of the cupola. The iron is tapped until the slag, which usually floats on the metal, is seen to be at the level of the opening. This occurrence shows that practically all of the metal has been drawn from the cupola and that the heat is terminated. The blast is then turned off and the bottom doors of the cupola are opened, allowing the materials still left in it, to fall to the floor beneath. This residue, which is usually slag and unburnt coke, is quickly extinguished and allowed to cool. When cool the coke is carefully separated from the slag. The coke, slag, and cast iron, resulting from the heat are then weighed separately on a Fairbanks scale, the data, with the other data obtained during the

heat being then used in making the thermo chemical calculations.

METHOD OF MAKING CALCULATIONS.

In melting a charge of iron in a foundry cupola there are two probable sources, by which the heat necessary to cause the fusion, is supplied. These sources are first, the coke, which furnishes the major part of the necessary heat, and secondly, the heat furnished by the oxidation of certain elements found combined with the iron, notably Silicon and Carbon.

Coke, which may be considered as carbon mixed with certain mineral matter, when heated, oxidizes in one of two ways depending upon the amount of air present during the oxidation. If burned with free access to the air, the carbon contained in it is changed to carbon dioxide, 8080 calories of heat being evolved for every kilogram of carbon burned.

$$C + O_2 = CO_2 + 8080 \text{ Cal.}$$

If however, insufficient air is provided, a partial oxidation results, with the formation of carbon monoxide, a gas having a calorific value of 2410 Cal.

$$2C + O_2 = 2CO + 3473 \text{ Cal.}$$

$$2CO + O_2 = 2CO_2 + 2410 \text{ Cal.}$$

In the calculations we desire to make a comparison

of the maximum amount of heat that the coke is capable ofgiving out with that actually utilized. As a basis for these calculations we will use as our unit the amount of heat that unit mass of coke when completely burned in oxygen, will give out. This value was determined by burning some of the fuel in a Mahler Bomb Calorimeter and found to be 7129 calories for every kilogram of coke.

Using this figure, we can say that the heat supplied by the coke expressed in calories, is numerically equal to the product of the weight of the coke used times 7129.

Calories supplied by coke = wt. of coke x 7129

The Silicon and carbon in the iron oxidize to some extent to Silicon dioxide and carbon dioxide respectively, each oxidation giving out heat. The manner of oxidation is given by the equations:

$$Si + O_2 = Si\,O_2 + 7407 \text{ Cal.}$$

$$C + O_2 = C\,O_2 + 8080 \text{ Cal.}$$

The actual amount of heat supplied by each of these sources is found in a manner similar to that used in determining the heat furnished by the coke, i.e. the amount of the element oxidized, times its calorific value. Summarizing, the heat supplied the cupola is calculated by the equations:

(1) By coke = wt. of coke x 7129 Cal.

(2) Oxidation of Silicon = wt. of Silicon lost from charged iron x 7407 Cal.

(3) By carbon in iron = wt. of carbon lost in iron x 8080 Cal.

UTILIZATION OF SUPPLIED HEAT.

(a) To heat up coke to melting point of iron.

The first substance to be heated by the fuel during the heat is the fuel itself, which must have its temperature raised from room temperature to that of the iron it is to melt. The amount of heat required for this purpose is found by multiplying the weight of the coke used by the number of degrees centigrade through which it has to be raised, times its specific heat. By ~~its~~ the specific heat of a substance is meant the number of degrees centigrade through which one calorie of heat will raise the substance. Coke has two specific heats depending upon the temperature to which it is heated. If heated to any degree less than 250°C, its specific heat is .201, while from 250° degrees it becomes .2337. Hence to find the heat utilized by the coke, we first find the amount of heat necessary to raise its temperature to 250 degrees centigrade, and add to this amount, the amount necessary to heat it from 250 deg.Cent. to the melting point of iron.

The equation for calculating this amount is as follows:

Heat required $=$ M x (250-T) .201 $+$ M (T 1 - 250) x .2337

Where T $=$ room temperature
T 1 $=$ temperature of the iron.

FOR HEATING UP LINING OF CUPOLA.

The second means of utilizing the heat supplied, is the necessity of heating the brick lining of the cupola . Assuming the temperature of the brick work to be the same as that of the heated gases leaving the cupola, and knowing the specific heat of brick, we can calculate the necessary heat by means of the following equations:

Heat required for heating brick work $=$ W (T 1-T2)S

Where W $=$ wt. of the brick work
S $=$ specific heat of brick
T1 $=$ Final temperature of brick work
T2 $=$ Room temperature

TO DECOMPOSE THE LIMESTONE.

The limestone, which was found to be a mixture of the carbonates of calcium and magnesium, during the heat is heated to 800 deg. cent., when the carbon dioxide is driven off and the stone reduced to the oxide.

$MgCO_3 + CaCO_3 = MgO + CaO + 2CO_2$

The heat utilized by the limestone is for a twofold purpose, first, to heat the mineral to decomposition temperature and secondly, to decompose it. It has been found experimentally that 167.88 cal. are required to

decompose 1 kilogram of limestone. Useing this value, the total amount of heat necessary for the heating and decomposition can be calculated from the equation:

Heat required = W x (800-T)x S + 167.88x W

Where W = wt. of limestone
T = Room temperature
S = Specific heat of limestone

TO MELT THE IRON AND SUPERHEAT IT.

The fusion of the iron should utilize the greater part of the heat supplied to the cupola. The amount of heat necessary for this purpose can be determined by the equation:

Heat required = W x (T-T1) S + W L + W x (T2-T)S1

Where W = wt. of the iron melted
T = melting point of iron - 1200 Deg.C.
T1 = Room temperature
T2 = Max Temp of iron
S = Specific heat of iron when solid
S1 = " " " " liquid.

HEAT NECESSARY FOR SLAG FORMATION.

The number of calories necessary for forming slag is found by multiplying the wt. of the slag formed by 550, the number representing in calories the heat necessary to form 1 kilogram of the slag.

Heat necessary = wt. slag x 550 cal.

HEAT LOST IN FLUE GASES.

One of the greatest losses in iron fusion is caused by heat being carried from the cupola in the flue gases.

In order to calculate this loss, the weight of the air passing through the cupola during the entire heat must first be determined. The method of procedure is as follows: We are given the pressure of the blast due to its velocity from readings taken with the Pitot tube and expressed in inches of water. A pressure of 1 inch of water is equivalent to a head of 70 ft. of air, therefore Pitot tube readings expressed in feet of air can be obtained by multiplying by 70. By a fundamental formula it can be shown that the velocity of a gas in feet per second is equal to the square root of the velocity head expressed in feet of air times twice the attaction of the earth due to gravity.

$$V = \sqrt{2\,GH}$$

Knowing the velocity, we can get the volume of gas by multiplying the velocity by the area of the orifice through which it is discharged.

Vol. = Velocity x area of orifice = cu.ft. per sec.

1 cu.ft. = .0283 cu.meters

therefore Vol. per sec. in cu. M. = Vol. in cu.ft.x.0283.

1 cu. M. of air weighs 1.293 kilograms, therefore the weight of the air used during the run is equal to the volume times 1.293 or

W = 1.293 x Vol. per min.x length of run in min.

HEAT LOST BY INCOMPLETE COMBUSTION OF CARBON.

Another loss of heat is caused by the passing off of carbon monoxide in the flue gases. CO could yield on oxidation 2410 cal. per kilo., therefore for every kilo. of CO present in the gases we have a loss of that amount. The heat lost by this means may be determined by the equation:

Heat lost = wt. of gas x per cent of CO x 2410

LOSS BY RADIATION.

One source of loss of heat is by radiation. This loss has been determined in heats held in 1908, when it was found to be approximately 7574 cal.

THERMAL EFFICIENCY OF THE CUPOLA.

The thermal efficiency of the cupola is defined as the ratio of the total amount of heat supplied to the cupola and that actually necessary ~~in~~ for fusing the iron.

$$E = \frac{\text{heat necessary to fuse iron}}{\text{" supplied to cupola}}$$

DATA AND CALCULATIONS.

I

Data Of Heat Held November 12th, 1908.

CHARGE.

Coke	240 kilograms
Scrap iron	727 "
Pig iron	363.5 "
Limestone	70 "

ARRANGEMENT OF CHARGE.

Bed charge of coke	136 kgms.
Scrap iron	362.0 "
Coke	22.7 "
Scrap iron	91.0 "
Pig iron	91.0 "
Limestone	18.0 "
Coke	27.1 "
Scrap iron	91.0 "
Pig iron	91.0 "
Limestone	18.0 "
Coke	27.1 "
Scrap iron	91.0 "
Pig iron	91.0 "
Limestone	18.0 "
Coke	27.0 "
Scrap iron	91.0 "
Pig iron	91.0 "
Limestone	16.0 "

Results Of The Heat.

Cast iron	1065 kgms.
Slag	119.5 "
Unburnt coke	93.0 "

The blast was turned on at 337 P.M. and the drop occurred at 4.44 P.M., giving a total run of 67 minutes.

TEMPERATURES.

Room temp.-----------------------------20°C

Temp. of the escaping gases(taken every 3 min).

Highest-----------------------------1280°

Lowest--------------------------------155°

Average------------------------------700°

Temperature of the iron(taken at each tapping).

Highest-------------------------------2450.°

Lowest--------------------------------1700.°

Average--------------------------------1900.°

BLAST DATA

Mean static head(taken every 5 min.). ---4.5" water.

" dynamic -" " " " ---5.076" "

" velocity " " " " ---.570" "

" radius of discharge orifice-----------3".

ANALYSIS OF MATERIALS.

	PIG IRON	SCRAP IRON	CAST IRON
Si	2.50	2.12	2.30
G.C.	4.19	2.65	2.35
C.C	.25	.55	.60
T.C.	4.44	3.20	2.95
Mn.	.94	.45	.55
P.	.55	.179	.39
S	.03	.066	.023

ANALYSIS OF THE LIMESTONE.

SiO	.26%.
Fe O- Al O	.69.
Ca O	30.6
Mg O	21.14.
P	0.0.
S	0.0.

ANALYSIS OF THE SLAG.

SiO	51.67
Fe O	12.50
Al O	1.35
Mn O	8.92
P	0.0.
CaO	12.76
MgO	5.23
S O	.44

ANALYSIS OF THE ESCAPING GASES.

CO	14.0
O	0.0
CO	1.2

ANALYSIS OF THE COKE.

Moisture	.23
V.C.M.	1.33
F.C.	88.24
S	·91
P	.23
Si O	4.58

Al_2O_3	2.9
Fe_2O_3	1.27
Ca O	.23

CHARGE.

COMPOSITION OF MIXED CHARGE OF PIG AND SCRAP IRON.		COMPOSITION OF RESULTING CAST IRON.	CHANGE IN COMPOSITION.
Si	2.24	2.30	+ .06
G.C.	3.26	2.35	- .91
C.C.	.46	.60	+ .14
T.C.	3.72	2.95	- .77
Mn	.61	.55	- .06
P	.30	.39	+ .09
S	.054	.033	- .021

CALCULATION OF THE HEAT DEVELOPED.

Wt. of coke used in heat------------------------147kgms.

Wt. of iron melted---------------------------1090 "

Calorific value of coke---------------------7129 Cal. per kgm.

Per cent silicon oxidized-------------------.06

" " Carbon " --------------------.77

Heat supplied by coke = 147x 7129= 1, 048,000 calories.

By silicon- .0006x7407x1090= 48,44 "

By carbon in iron- .20x1090x8080= 58,127 "

Total heat supplied to the cupola 1,110,971 "

CALCULATION OF THE HEAT UTILIZED.

1. In Heating Coke.

Weight of Coke	147 kilograms.
Initial Temperature of coke	20° C.
Final " " "	1900° "
Specific heat of coke if below 250 degrees	.201
" " " " "above " "	.2337

No of Calories req.= 147(250-20).201=147(1900-250).2337.= 66,556

2. In Heating Brick Lining of Cupola.

Diameter of Cupola	.57 m.
Height	2 m.
Thickness of Brick work	.11 m.
Weight of brick	2003 kilo per cu.M.
Initial Temperature	20°C
Final Temperature	700°
Specific Heat of brick	.26

Heat req:=2003x($\pi .395^2-\pi .285^2$)2x(700-20).26=182,800 calories.

3. In Decomposing the Limestone.

Weight of Limestone	70 kilo.
Decomposition temperature of Limestone	800° C.
Heat necessary to decompose 1 kilo. of Limestone	167.88 cal.

Heat req.=70(800-20)26+70x167.88=25,940 cal.

4. In Melting and Superheating the iron.

Weight of iron	1090 kilo.
M.P. of iron	1200°C.
Specific heat of iron when solid	.1124
" " " " liquid	.22
Final temperature	.1900°C.

Heat of fusion of iron 69 cal. per kilo.

Heat req.=1090x.1124(1200-20)+1090(1900-1200).22+1090x69=390,110 cal.

5. For Slag formation.

Weight of Slag 119.5 kilo.

Heat of Slag Formation 550 cal.

Calories required =550x119.5=65,720 cal.

6. Heat lost in flue gases.

(a) Blast calculations.

Velocity head=.576"water=70x.576=40.32 ft.air

Velocity = GH-2Gx40.3-50.8 ft. per sec.

Vol. air per sec.=velocity x area of orifice.

" " " " $\frac{\pi 3^2 \times 50.8}{144}$ =9.64 cu. ft. per sec.

" " " " 20.2 cu.m. per min.

Weight of air used in run =67x1.293x20.2=1463 kilograms.

(b) Heat lost.

Temperature of gases 700 Degrees.

Specific heat .2374

Heat lost in gases =1463x(700-20).2374=236,000 cal.

7. Carried off by the C O in flue gases.

Per cent of C.O. in flue gases 1.2

Calorific value of C O 2410 cal.

Loss of heat =1.2 per cent x1463x2410=42,280 cal.

S U M M A R Y.

Heat supplied to the Cupola.

By Coke.	1048000 cal.
By Silicon.	4844
By carbon in iron.	58127
Total	1,110,971

To Heat utilized in Cupola.

In Heating up Coke.	66,556
" " Brick work.	182,800
In Decomposing Limestone.	25,940
In Heating Iron.	390,110
In forming Slag.	65,720
In Flue Gases.	236,000
By C O.	42,280
By Radiation.	7574
Total	1,016,980 cal.

Unaccounted for. = 8.48 %

Thermal efficiency of cupola.

$$E = \frac{390,110}{1,110,971} = 38\%$$

Data and Calculations of heat held Feb.16,1909.

C H A R G E.

Scrap iron	1000	kilograms.
Pig iron	1224.7	"
Coke	188.24	"
Limestone	36.29	"

ARRANGEMENT OF CHARGE.

Bed Charge of Coke	136	"
Scrap iron	408	"
Coke	22.6	"
Limestone	9.07	"
Scrap iron	181.5	"
Coke	22.6	"
Limestone	9.07	"
Scrap iron	181.5	"
Coke	18.15	"
Limestone	9.07	"
Pig iron	90.7	"
Scrap iron	90.7	"
Coke	18.15	"
Limestone	9.07	"
Pig iron	90.7	
Scrap iron	90.7	
Coke	4.53	"
Pig iron	45.3	"
Scrap iron	45.3	"

DURATION OF RUN.

Blast on at 2.40 P.M.

First iron at 2.58 A.M.

Drop at 3.38 P.M.

Time of run 58 minutes.

RESULTS OF HEAT.

Good castings	812 kilograms.
Bad Castings	337 "
Total Cast Iron	1149 "
Weight of Slag produced	59 "

TEMPERATURES.

Room Temperature	20°C.
Temperature of gases	700°C.
Temperature of metal	1700°C.

BLAST DATA.

Static Head	6.1" water.
Velocity head	1.061 "
Dynamic "	7.161 "

ANALYSIS OF MATERIALS.

	PIG IRON.	SCRAP IRON.	CAST IRON.
Si.	2.50	2.35	1.88
G.C.	4.19	2.74	2.60
C.C.	.25	.50	.565
T.C.	4.44	3.24	3.165
M.n.	.94	.564	.396
P.	.55	.78	.596
S.	.03	.065	.07

ANALYSIS OF SLAG.

SiO_2	45.05%
FeO	11.3
AlO	14.4
CaO	16.53
Mn	.41
MgO	10.52
P.	.19

ANALYSIS OF FLUE GASES.

	No.1	No.2.	No.3	No.4	No.5	AVERAGE.
CO	5.7	1.4	.2	3.2	11.8	4.46
O	2.3	1.4	1.93	2.6	2.2	1.8
CO	10.2	9	9.64	6.0	7.0	8.37
N	82.8	89.2	89.2	89.2	79	

Analysis of Coke and Limestone same as in Heat 1.

CALCULATIONS.

CHARGE.

Per cent of elements in the mixed charge of pig & scrap iron		Composition of resulting cast iron	Change in Composition.
Si	2.75	1.88	- .87
G.C.	2.81	2.60	- .21
C.C.	.45	.565	+ .11
T.C.	3.48	3.16	- .32
Mn	.63	.396	- .24
P.	.738	.596	- .14
S.	.062	.07	+ .008

CALCULATIONS OF THE HEAT DEVELOPED.

Weight of coke used.	188.24 kilo.
Weight of iron melted,	1224.7 "
Cal. Val. coke,	7129 cal.per kilo.
Per cent of Silicon oxidized,	.86
" " " Carbon lost from iron	.32

Heat given out by coke= 7129x188.24=1.341,000

" " " " Sil.= 7407x .86%x1224= 7797

" " " " Carbon=8080x .32%x1224= 3165

Total Heat supplied---------1,352,962

CALCULATION OF THE HEAT UTILIZED.

1. In Heating the coke.

Weight of coke,	188.2 kilo.
Initial Yemperature,	20°C.
Final Temperature	1700°C.

Heat req.=188.2(250-2).201+188.2(1700-250).2337=72,401 Cal.

2 In Heating the brickwork

Weight of Brickwork	1034 kilo.
Final Temperature	700° D.C.

Heat req.=1034(700-20).26=182,800 cal.

3 In Decomposing Limestone.

Weight of Limestone.	36.29 kilo.

Heat req.=36.29(800-20).26+167.88x36.29=13,450 cal.

4. In melting and superheating the iron.

Weight of iron 1224.7 kilo.

Final Temperature. 1700 C.

Heat req. = 1224.7(1200-20).1124 + 1224.7(1700-1200).22 +

69x1224.7 = 397,660 Cal.

5. For Slag Formation.

Weight of Slag 59 kilograms.

Heat required to form slag = 59x550 = 32,410 cal.

6. Heat lost in Flue Gases.

(a) BLAST CALCULATIONS.

Velocity head = 1.061" water = 1.061x70 = 74.27' of air.

Velocity in ft. per sec. = $\sqrt{2G\times 74.27}$ = 68.6' per sec.

Vol. in cu.ft. per sec. $\pi \frac{68.6\times 3^2}{144}$ = 13.03 cu. ft. per sec.

Vol. in cu. m. per min. = 21.96

Weight of air used furing run = 21.96x1.293x58 = 1647 kil.

(b) Heat Lost.

Final Temperature of gases 700°C.

No. of Cal. lost = 1647(700-20).2374 = 265,900 cal.

7. By C O Flue Gases.

Per cent C O in gases 8.37

Heat Lost = 8.37%x1647x2410 = 332,000 cal.

S U M M A R Y .

Heat Supplied to Cupola

By Coke,	1,341,000
By Silicon,	7,797
By Carbon lost from iron	3,165
Total	1,352,962

Heat Utilized in Cupola.

In Heating up coke,	72,401
In heating up brickwork,	182,800
In Decomposing Limestone,	13,450
In Heating Iron,	397,660
In Forming Slag,	32,410
In Flue Gases,	265,900
By C O	332,000
By Radiation,	7,574
Total	1,304,195 cal.

Per Cent unaccounted for 3.56

Thermal efficiency -397,660-1,352,962= 29.5%

Practical efficiency $= \frac{\text{Output}}{\text{Input}} = \frac{1149}{1224} =$ 94%

DATA AND CALCULATIONS FOR HEAT
HELD MARCH 26th, 1909.

111

C H A R G E .

Coke --136 kilo.

Pig Iron------------ ----------------------739.88 "

Limestone-------------------------------------- 27.21 "

ARRANGEMENT OF CHARGE.

Bed Charge of Coke----------------------------136 kilo.

Limestone------------------------------------- 13.6"

Pig iron--116 "

Coke--18.15

Pig iron--115.8

Coke--13.6

Pig iron--116.1

RESULT OF HEAT.

Cast iron---------------------------------------601.5

Slag-- 49.2

T TEMPERATURES.

Room temp.------------ ------------ 27.3°

Temp. of escaping gases------------------875° D.

Temp. of iron----------- ------- ---- 1641° D.C.

BLAST DATA.

Static Head--------------------------------- 4.48"of water

Velocity head----------------------------- .468" "

Dynamic Head---------------------------- 5.948" "

ANALYSIS OF MATERIALS.

	PIG IRON.	CAST IRON.
S i	2.50	2.73
G.C.	4.19	3.26
C.C.	.25	.45
T.C.	4.44	3.71
M.n.	.94	.61
P.	.55	.51
S.	.03	..03

ANALYSIS OF SLAG.

S i 02	44.98%
F e 0	13.15
A l 0	17.05
C a O	26.4
M n	6.5
P.	.11

ANALYSIS OF LIMESTONE.

S i 02	.94%
F e 0 - A l 0 - .60	.60
C a O	54.7

ANALYSIS OF FLUE GASES.

	No.1	NO.2	NO.3	NO.4	No.5	No.6
CO.	11.4	14.8	13.6	14.6	13.9	7.2
O.	.2	0	0	0	0	2.8
CO.	.4	1.6	1.1	1.3	3.8	2.2

A V E R A G E.

CO---------------------------------- 11.6
O----------------------------------- .5
CO---------------------------------- 1.7

The Analysis of Coke used in this heat is identical with the Analysis of that used in the preceeding heats.

CALCULATIONS.

(a) CHARGE.

Per cent of elements in charge		Percentage of elements in cast iron expressed in terms of input.	Percentage Change in Composition.
Si	2.5	2.23	-.27
G.C.	4.19	2.63	-1.56
C.C.	.25	.35	+.10
T.C.	4.44	2.98	-1.46
Mn	.94	.508	-.44
S.	.03	.024	-.006
P.	.55	.417	-.133

CALCULATION OF THE CALORIES DEVELOPED.

Weight of Coke	166 kilograms.
Weight of iron	739.38 "
Per cent of Silicon lost in iron	.27 "
" " " Carbon " " "	11.46 "
Heat Supplied by Coke =166x7129=	1,186,000 cal.
" " " Silicon=7407x.27%x739=	14,780
" " " Carbon =8080x1.46%x739=	86,460
Total Heat Supplied---------------	1,287,240 cal.

CALCULATION OF HEAT UTILIZED.

1. In heating the coke

Weight of coke 166 kilograms.

Final Temperature 1840° D.

Initial Temperature 27.3°

Heat req.=166(250-27.3).201+166(1840-250-.2337=69,134 cal.

2. In heating brickwork,

Weight of Brickwork 1034 kilo.

Final Temperature 875°C.

Heat req.=1034(875-27.3).261=230,700 cal.

3. In Decomposing the Limestone.

Weight of Limestone 27.21 kilo.

No. Cal req.=27.21(800-27.3).26+27.21x167.88=10,034 cal.

4. In Melting and Superheating the Iron.

Weight of iron 739.38 kilo.

Final Temperature 1840° C.

Heat Req.=739x.1124(1200-27.3)+739x.22(1840-1200)=207,272 calories.

5. In Forming the Slag.

Weight of Slag 49.2 kilo.

Heat req.=49.2x550=27000 cal.

6. Heat lost in Flue gases.

(a) Blast Calculations.

Velocity head = .468" water =32.76' of air.

" in ft. per sec.=$\sqrt{2\,G\times 32.76}$=45.8' per sec.

Vol. in cu. ft. per sec.=$\frac{45.8\times\pi 3^2}{144}$=8.7 cu.ft.per sec.

Vol. - 14.7 cu.M. per min.

Weight of air used during run -14.7x1.293x60-1141 kilogrms.

CALCULATION OF HEAT LOST.

Final Temperature of gases 875 ° C.

Heat Lost in Gases -1141(875-27.3).2374-232,300 cal.

7. Heat lost by the C O .

Per cent of C O in gases - 1.7

Calories lost - 1141x1.7%x2410-46,720 cal.

S U M M A R Y.

Heat Supplied to Cupola.

By Coke	1,186,000
By Silicon,	14,780
By Carbon lost from iron	86,460
Total Heat Supplied to Cupola	1,287,240 cal.

HEAT UTILIZED IN CUPOLA.

In Heating up Coke	69,134
" " " Brickwork,	230,700
" Decomposing Limestone,	10,034
""Heating the iron,	207,272
" Forming the Slag	27,000
By the Flue gases	232,200
By C O .	46,720
By Radiation	7,574
Total	830,634 calories.

Heat Unaccounted for 35.4%

Thermal Efficiency 16.2%

Fig.8.

No.1 Pig Iron.

D I S C U S S I O N.

(a) The Foundry Irons.

The iron as used in Foundry practice is of two general classes, Pig iron and scrap iron. Pig iron is defined as iron which has been taken directly from a Blast Furnace, i.e. it has never been remelted since its initial reduction from the ore. Scrap iron is iron which has been remelted one or more times since leaving the Blast Furnace. Both consist of the element iron, (Fe) combined with greater or less amounts of Silicon, Manganese, Phosphorus, Sulphur, and Carbon, the percentage of these elements present determining the physical character of the iron, as well as its adaptability for the different purposes for which it is intended. For most efficient Foundry practice, it is essential that a thorough knowledge be had of the individual effects of each of the elements upon the iron, in order to aid in so proportioning the charge as to contain more of the desired elements than those detrimental to the iron. It is my purpose to discuss briefly each of the above elements, both as regards their probable state of combination with, and effect on the iron in which they exist.

CARBON.

The first component of the iron to be discussed is Carbon which always is present in the largest quantity of all the elements. Carbon ~~and~~ in iron results from two causes,

the first being the tendency of the iron to unite chemically with the element forming a carbide, and secondly, depending upon the ability of molten iron to dissolve carbon. As the result we always find carbon present in iron in two forms, the graphitic, or uncombined form, and secondly the carbide of iron. The first form, being merely a foreign substance which has crystallized from the iron on cooling, but which still coheres to the metal, gives the iron a characteristic gray graphitic appearance. It also tends by being interposed between the iron particles to break the continuity of the metal and thus weaken it. Its presence also causes the melting point of the iron to be lowered from 1587 degrees to 1220 degrees Centigrade. There are two distinct advantages in having graphitic carbon present in the iron. First, by virtue of its breaking the continuity of the iron, it softens the metal rendering it easy to machine or work. Secondly, it reduces shrinkage by expanding the iron while solidifying, by crystallizing out at that point. Lastly, it counteracts the hardening effects due to the presence of combined carbon. As practically all castings have to be filed, chipped, or machined, before they can be used for the purpose for which they were intended, the advantage of having a soft metal to work with is obvious and well worth sacrificing a little of the strength of the metal..

For this, if for no other reason, the founder should see that his cast iron, and hence his pig or scrap irons, have a considerable amount of this form of carbon. Good foundry iron should have from 2.5 to 4% of graphitic carbons.

Combined carbon, or the second form is more or less of an undesirable element to have in the iron. It is present in the iron largely as Ferric Carbide Fe_3C, a definite compound. Its chief effect is that it causes hard, close grained, and not easily machined castings to be formed, fitting the iron for a very limited class of work. In small quanitities and in the presence of much graphitic carbon it is of advantage as it adds strength to the iron, which at the same time will be soft enough to machine, On account of the presence of the other form of carbon.

SILICON.

Silicon probably exists in iron as a Silicide, FeSi. Like graphitic carbon it is a desirable element in cast iron. Its desirability is due to the fact, that if present in from 1 to 4% of the iron, it prevents the formation of combined carbon,causing the carbon in the iron to be changed to the graphitic form.

Reference: "Hoffman's Iron and Steel." Page 86-89.

By this property it tends to reduce the shrinkage of the iron and also to soften it. Sulphur however, reduces this power of the Silicon, .01% Sulphur being able to counteract the effects of .0.15% Silicon. .15% Silicon can prevent the formation of .03% combined carbon. An additional advantage of the Silicon is that it imparts fluidity to the iron when molten, which is desirable. It is of greatest good to the iron when present in from 1 1/2 to 2 1/2%.

PHOSPHOR~~O~~US.

Phosphor~~o~~us in iron is usually present as a phosphide Fe_3P. Its general effects are on the whole detrimental to the iron. If present at below .8% it imparts fluidity to the metal and causes the iron to retain its heat for a longer time, at the same time affecting very slightly the strength of the iron. If present above .8% it causes brittleness and cold shortness to occur. At 1.2% it causes all the graphitic carbon in the iron to be changed to combined while at 1.6% a shock will break the casting. For most foundry work the phosphor~~o~~us contents should be between .5 and .8%.

MANGANESE.

Manganese is present in iron usually as an alloy. If present in quantities below 1% it strengthens the casting, but if between 1 and 1.5% it makes the iron brittle. Over 1.5% it weakens the metal considerably increasing its hardness and shrinkage. Its chief advantage is that it can counteract the effects produced by the presence of Sulphur, notably in decreasing the shrinkage. With a .75% Manganese present Sulphur may be present as high as .13% and yet have no bad effects upon the iron. Good cast iron should not have more than 1% Manganese.

SULPHUR.

Sulphur is present in the iron as a Sulphide, FeS. Its presence is injurious to the metal, as it causes the iron to run sluggishly and produces shrinkage and blow holes in the castings. .01% Sulphur can produce the shrinkage of .01 of an inch in a casting. However, as has been stated, the presence of sufficient Silicon will counteract this effect to some extent.

CLASSIFICATION OF THE FOUNDRY IRONS.

Taking into consideration the compensating effect of Silicon and Sulphur, a table has been prepared by which all of the iron suitable for foundry practice has been classified. The irons have been divided into four classes, the best iron being known as No.1, the poorest as No. 4. The classes are as follows;

ELEMENT.	NO.1	NO.2	NO.3.	NO.4
SILICON	2.75%	2.25	1.75	1.25
SULPHUR	.035	.045	.055	.065

A second classification is also made depending upon the phosphorous content of the iron. If the metal contains less than .8% phosphorous it can be used for castings which require strength as machinery, columns, etc. If more than .8% is present in the iron, by reason of its brittleness, the metal is suitable only for ornamental work, or work in which strength is not a requisite.

(B)

EFFECT OF REMELTING UPON IRON.

From the results of the heats held in the cupola I found that on remelting, iron loses some of the Silicon, Carbon, and Manganese, originally combined with it, the cast iron being less rich in those elements. There are two probable causes for this reduction, first being that the loss is a result of simple oxidation, due to the presence of an excess of oxygen in the cupola, while the second is that it is due to chemical reaction between the Limestone and the iron. Both causes seem very probable, but I think that the greater part of the loss is due to the first cause for the following reason:

In an effort to get a hot metal, the cupola temperature was allowed to go much higher than that of the melting point of iron. With the presence of the abundant oxygen furnished by the blast and the high temperature it seems impossible that substances like carbon, silicon, or manganese, whose affinity for oxygen is comparatively great, could be kept from oxidizing. Owing to the fact that so much iron is present, the oxidation cannot be complete, as the iron whose affinity for oxygen is also large, will prevent the complete removal of the elements by being oxidized itself. To substantiate this theory we find that there is present considerable iron in the slag, the metal having been oxidized and taken up by the ~~lime~~.

As regards the Limestone it is reduced to Calcium Oxide at 800°C according to the equation:

$$CaCO_3 + CaO = CO_2 - 167.88 \text{ cal.} + CaO.$$

and is very liquid at the temperature attained in the cupola. Being basic in its nature, it can and does unite with the oxides of iron, manganese, and silicon. This accounts for the fact that we find those metals chemically combined with the Lime in the Slag.

(C)

CUPOLA EFFICIENCY AND HOW OBTAINED.

Cupola efficiency in foundry practice, is defined as the ability of the cupola to produce economically the maximum amount of cast iron from the charge, which when poured will make good castings. This conception includes, besides the necessity of a low fuel ratio, certain other conditions which are equally as essential for obtaining the best results.

First among these conditions is the matter of temperature. It is evident, that no matter how near the molds may be to the cupola, there is considerable cooling of the metal between the interval of tapping from the cupola and pouring into the mould. This loss of heat must be compensated for by the founder, there being but one means of doing so, viz; by superheating the iron or heating it above its melting point.

This means that more than the amount of coke theoretically necessary to fuse the iron must be added to supply the additional heat. How much this excess should be for greatest economy of operation is a matter which can only be determined by repeated trials and experiments.

From the experience of different foundry men it has been found that for best results the amount of coke necessary in a charge is from 1/8 to 1/10 the weight of the iron to be melted. These figures show that approximately four times the amount of coke theoretically necessary for melting the iron has actually to be used.

DISTRIBUTION OF CHARGE.

Equally as important as the first consideration is the matter of the distribution of the charge. Like the former, the usual practice is the result of continued trials rather than of theoretical considerations. It has been found, that for best results the coke in the initial charge should be 1/3 the weight of the iron and for all subsequent additions the ratio should be 1 to 10. The object in having the first large charge of coke to bring the level of the iron above the blast opening, it having been found that the iron melts quicker when placed 6 to 8" above the opening. The second reason for such a distribution is that the first charge of coke has to provide abundant heat for heating up the cupola, and the presence of a large amount of coke increases the rapidity of this preliminary heating. An other condition universally

accepted as necessary, is to have the cupola filled at all times to the charging door with the charge. The object of this arrangement is twofold, first, it enables the charge while descending to utilize the heat being carried off by the hot gases, which would otherwise escape unused, and secondly, it insures a continuous supply of molten iron to the founder, as the descending charge on reaching the fusion zone is so nearly at fusion temperature that it melts immediately.

THE BLAST.

The next consideration to be taken into account is in regard to the blast, the first point being the time at which the blast should be started. Results of my tests, as well as of those of successful foundrymen seem to show that best results are obtained when the coke in the cupola is allowed to burn from one to three hours, depending upon the size of the charge and cupola, under natural draft before starting the blast. The advantages of this procedure are several. In the first place, it takes about six minutes after turning on the blast, if the cupola has been previously heated, to secure hot iron, while if no preliminary heating is resorted to the blast must be on from 30 minutes to one hour before fusion occurs.

As long as the blast is on, the power causing it must necessarily be utilized. Coke is cheaper than power, and as the expense for the power required for the extra 30 minutes in the second method is so much more than that incurred by burning the coke under natural draft for the same time in the first, it is evident that for economy if for no other reason the first method is the better one.

F L U X.

The addition of a Flux to the charge is an almost general practice among foundrymen. Its advantages are twofold. First, it promotes fluidity in the iron, causing the metal to run freely; secondly, by its chemical properties it separates the oxides of the iron, manganese, and silicon, from the molten mass of the iron by combining with them and causing them to float on the top of the metal as a slag. By this action a clean iron is produced. There is however, a slight disadvantage in the use of a flux which is most evident in a large heat. As the heat progresses, the bulk of the slag formed by the flux increases also, with the result that finally it does not separate easily from the iron but tends to flow out of the cupola with the metal, causing difficulty in procuring clean castings.

This occurrence was not experienced in any of the heats held in the school foundry as none of them were of very long duration. In heats, however, where it does occur, the percentage of iron affected by the slag is so small compared to the total amount melted that it is worth the while of the founder to risk losing that amount provided that he can secure the remainder of the charge in a very fluid and clean condition. The usual proportions for fluxes are about 30 lbs. of flux for every ton of iron.

The conditions mentioned above are practically all, which the founder desiring high cupola efficiency must meet, and if all are carefully taken into account by him, there is no reason why successful results should not follow.

----------THE END---------- --

R E F E R E N C E S   C O N S U L T E D.

"Metallurgical Calculations." Richards.

"The Foundry Cupola." Kirk.

"Foundry Practice." Tate & Stone.

"Iron and Steel." Hoffman.